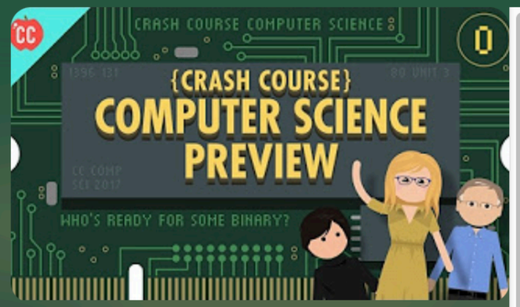
Computer Architecture

A gentle introduction

Josh Borrow, Jun 10th



Computer Science

CrashCourse

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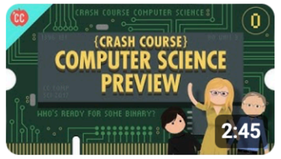
In 40 episodes, Carrie Anne Philbin teaches you computer science! This course is based on introductory college-level material as well as the AP Computer Science Principles guidelines. By the end of this course, you will be able to:

*Outline the history of computers and the design decisions that gave us modern computers
*Describe the basic elements of programming and software
*Identify the basic components of computer hardware and what they do
*Describe how computers are used and how that has evolved over time

1 

Crash Course Computer Science Preview

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Early Computing: Crash Course Computer Science #1

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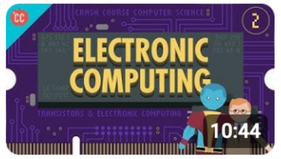
3 

Electronic Computing: Crash Course Computer Science #2

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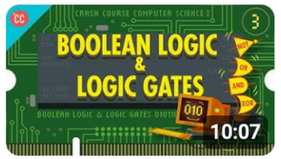
4 

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Representing Numbers and Letters with Binary: Crash Course Computer Science #4

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How Computers Calculate - the ALU: Crash Course Computer Science #5

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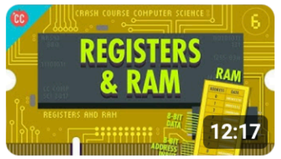
7 

Registers and RAM: Crash Course Computer Science #6

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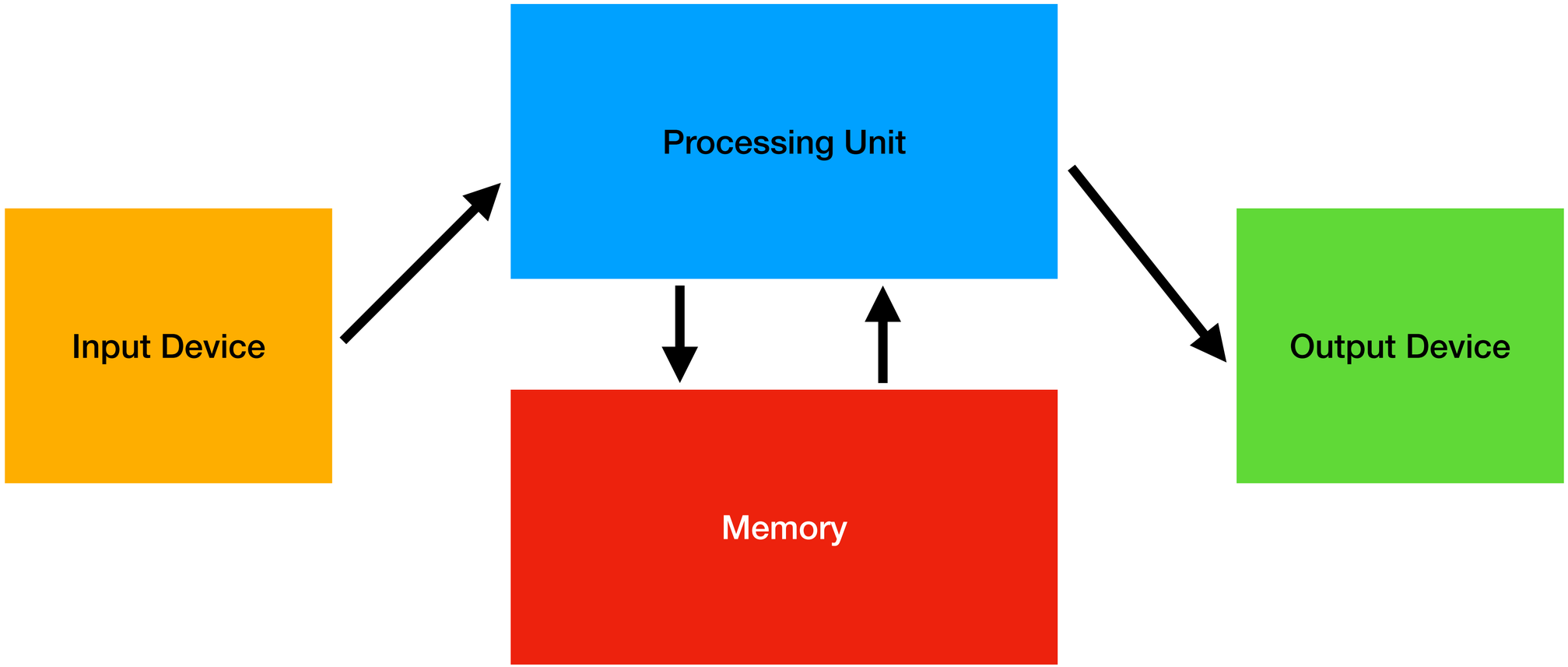
But… Software?

- As all your software runs on hardware, it’s crucial to understand it.
- Even a **base-level knowledge of computer architecture** can help you write vastly more performant programs.
- Knowing your hardware also comes in clutch when debugging programs.

A basic ‘computer’



ASUS
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Hard Drive

SATA DMA
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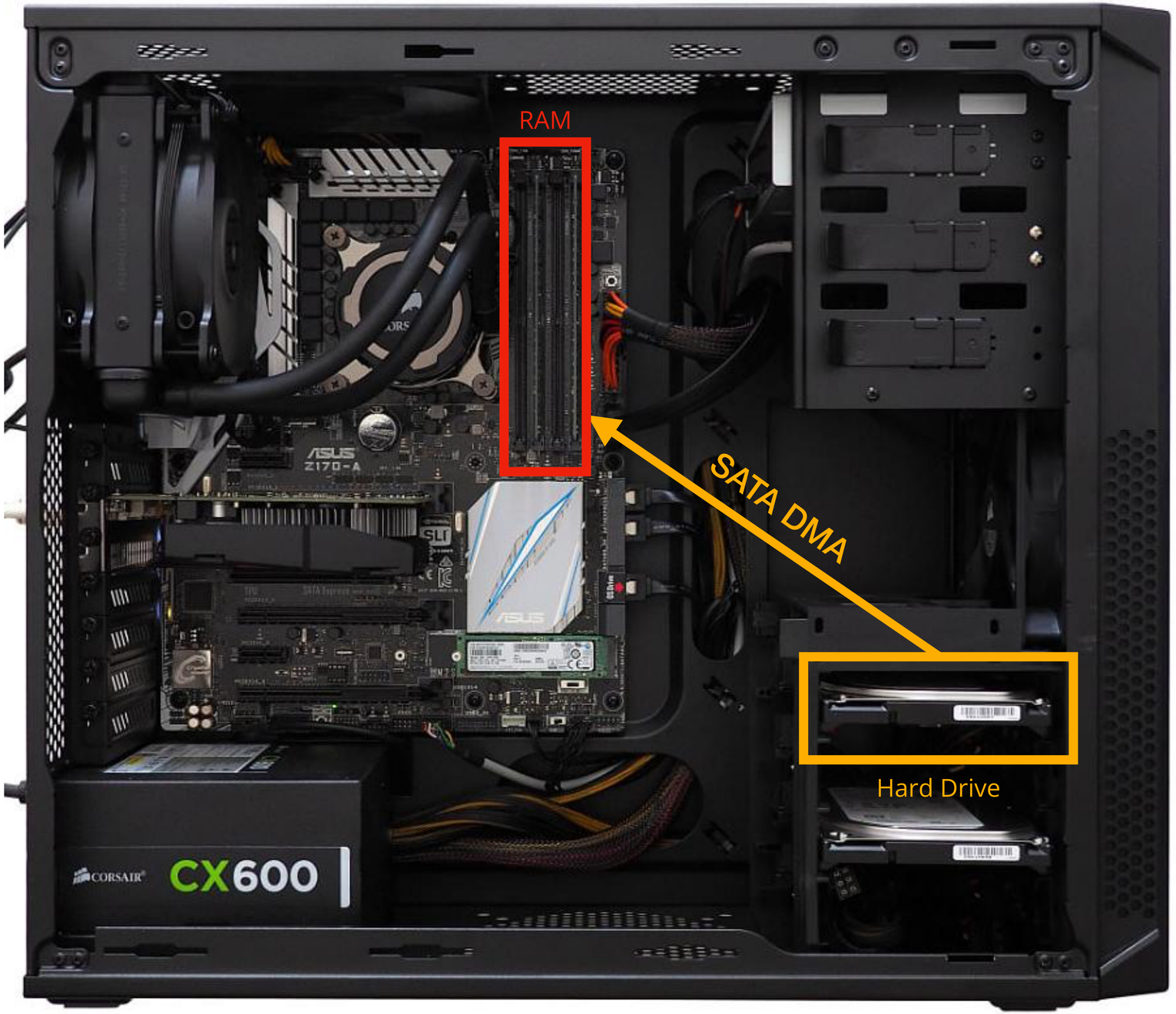
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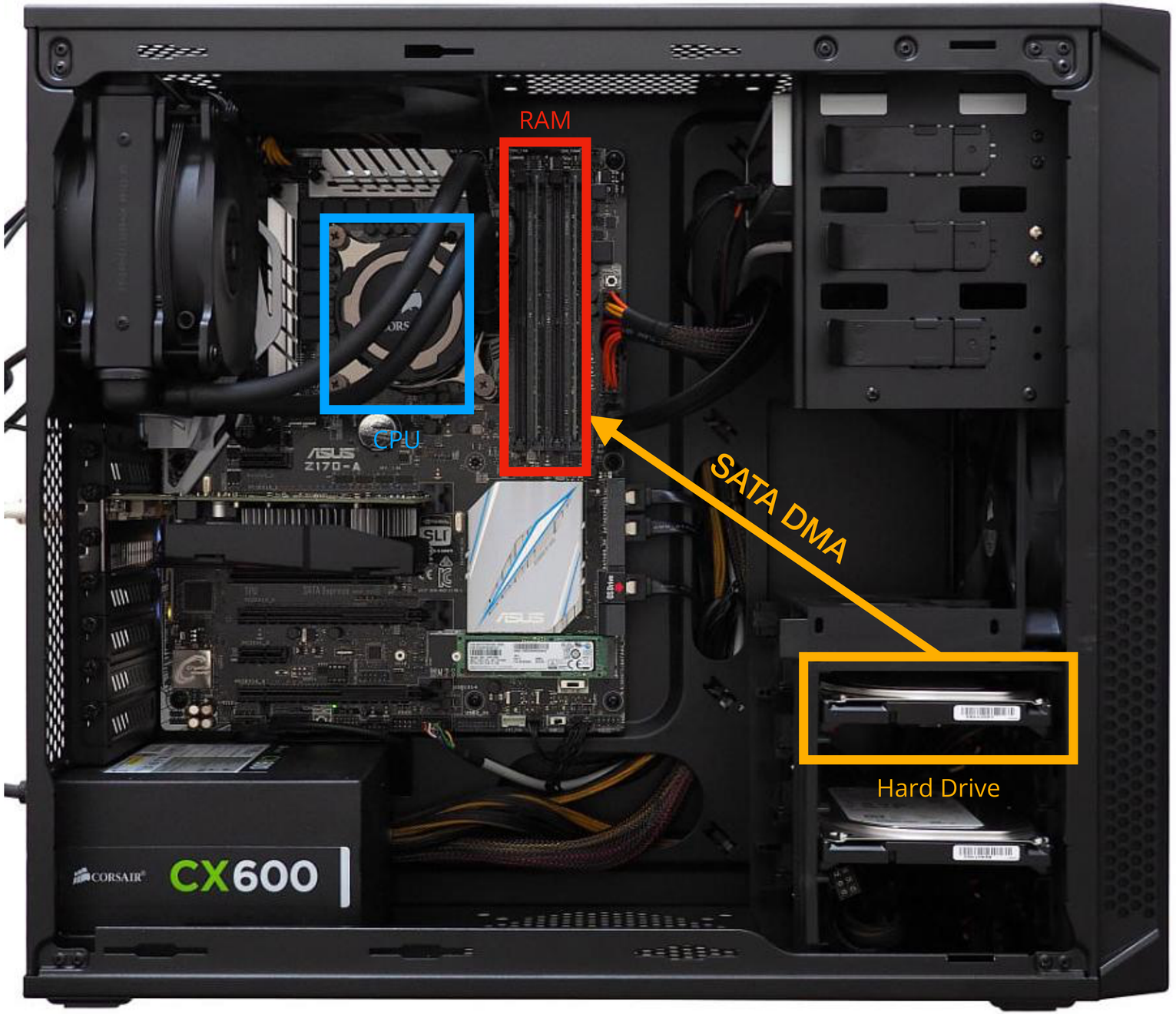
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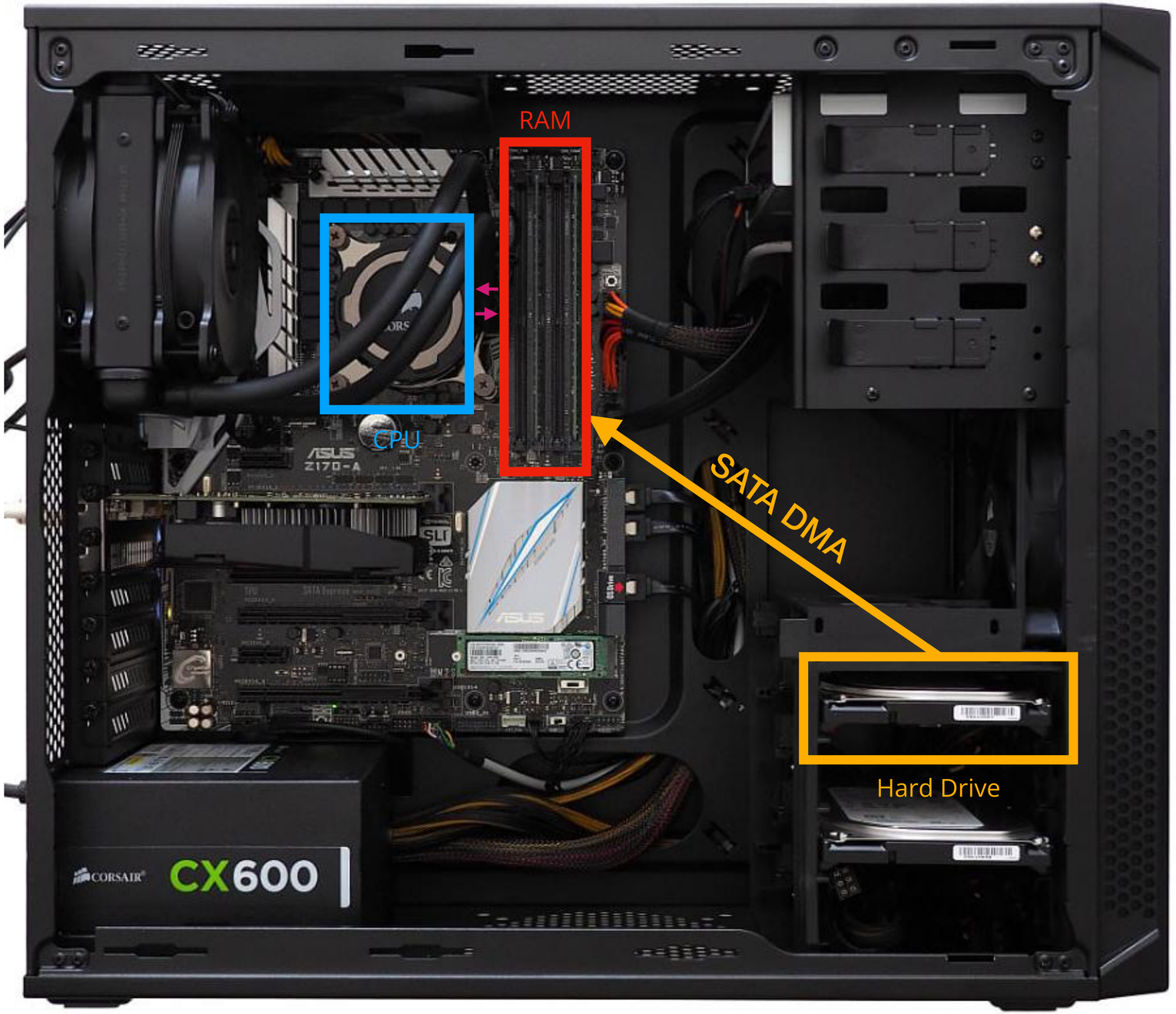
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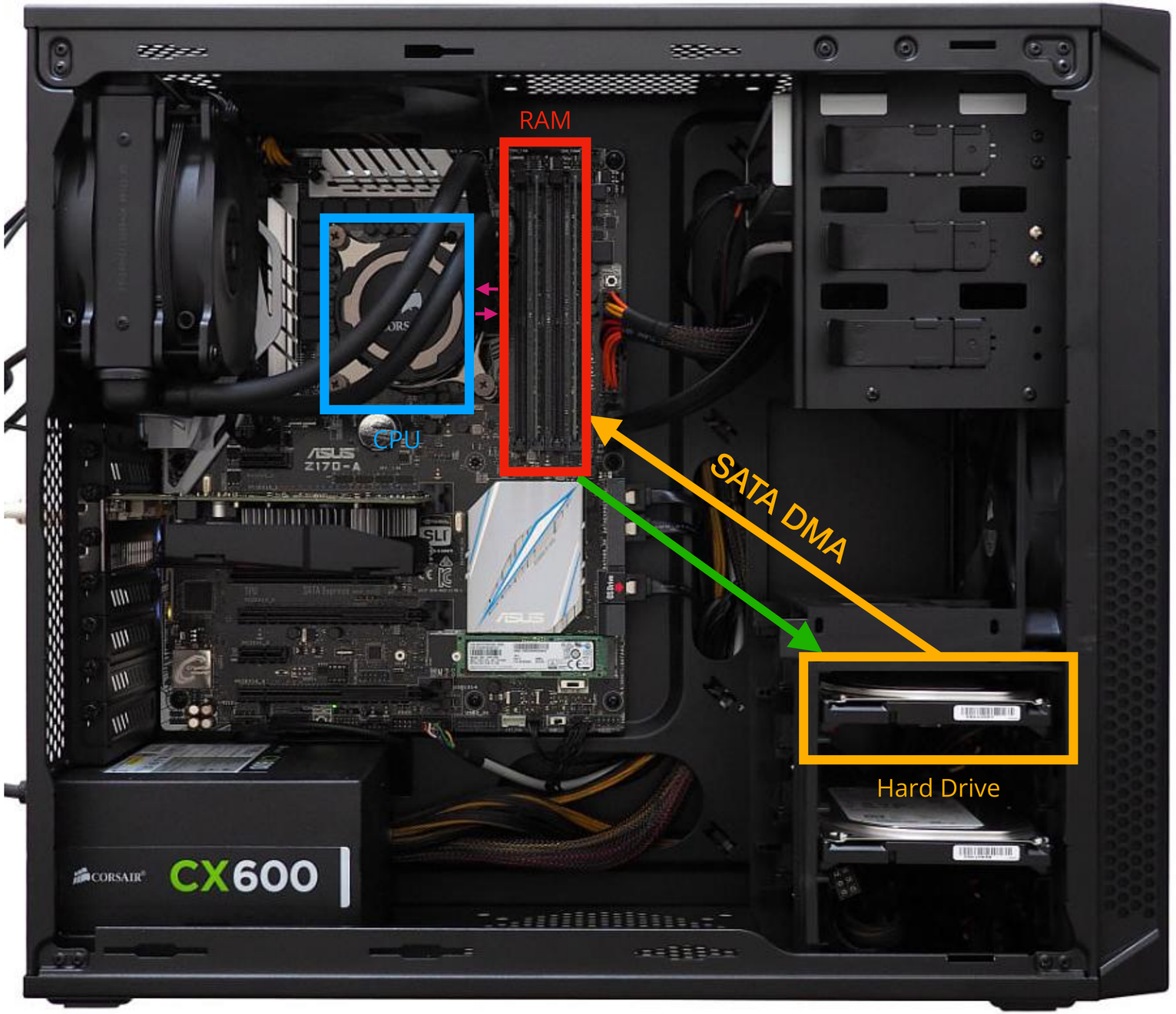
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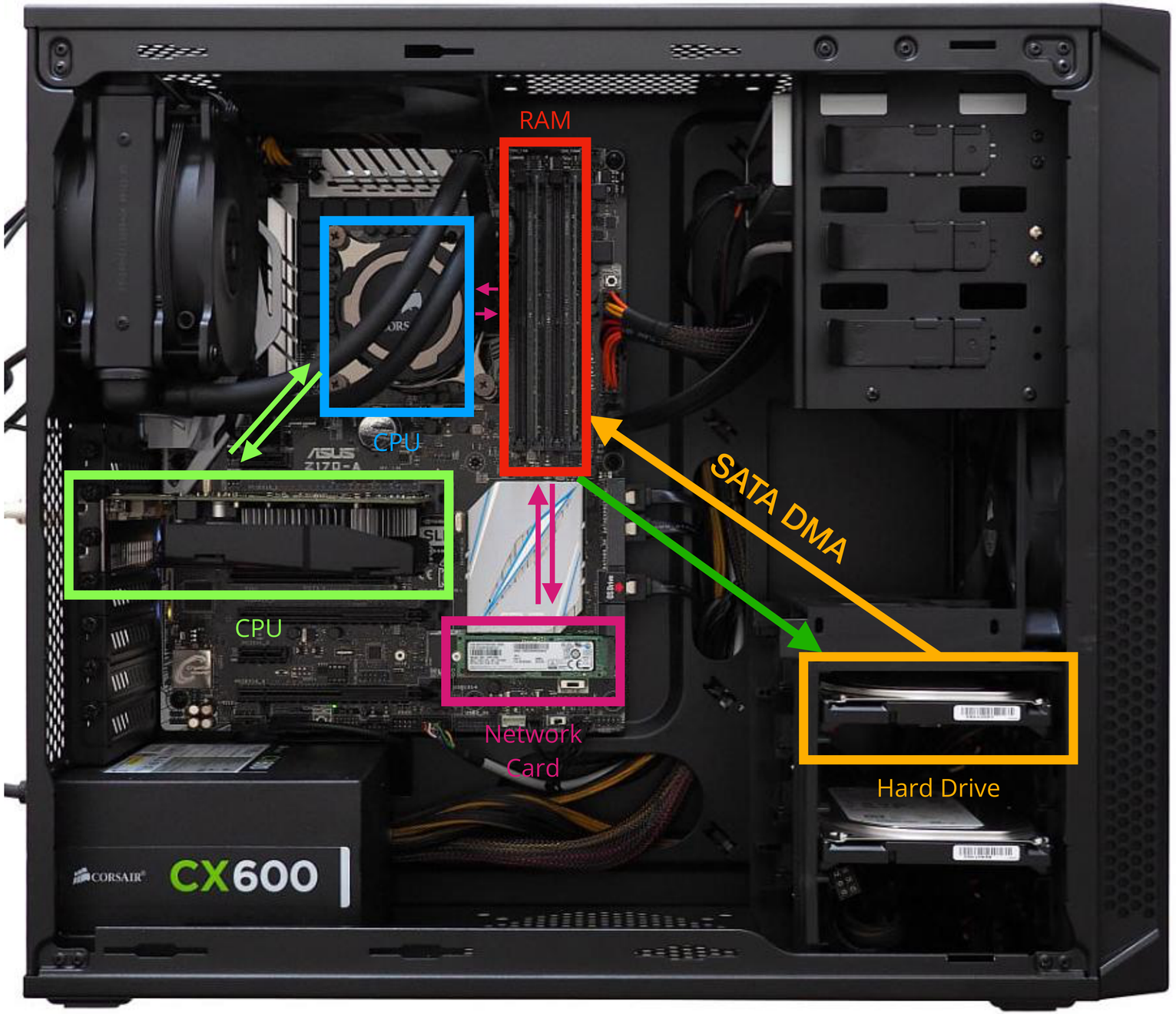
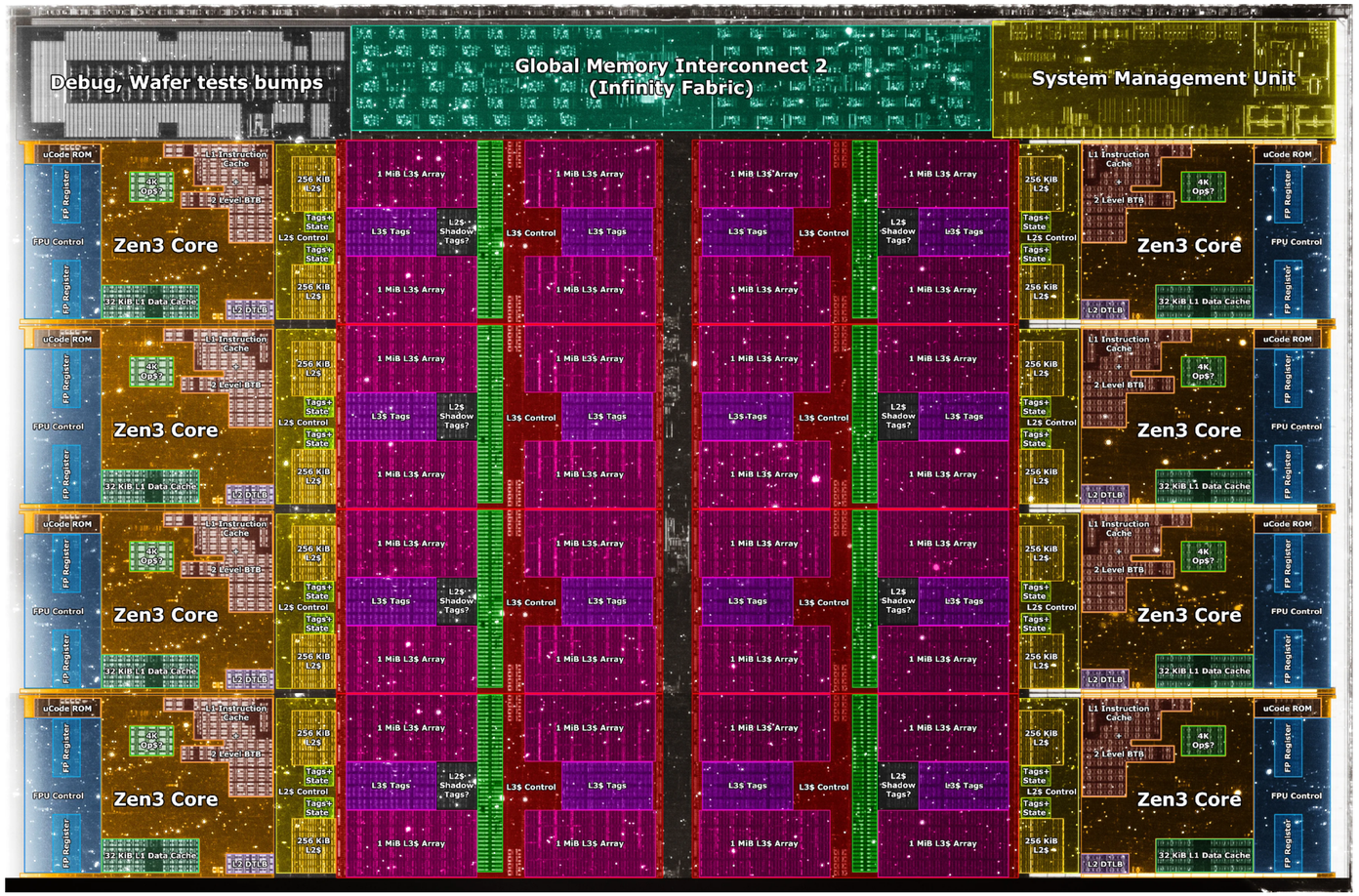

RAM
CPU
CPU
SATA DMA
Network
Card
Hard Drive
CORSAIR
CX600

Network
Node
CPU + Memory
Storage

But what is the CPU?

- The CPU, at a hardware level, is a very messy **integrated circuit**!
- It has lots of components, but at the end of the day its main goal is to do math, as quickly as possible.
- **Modern CPUs** are made up of **'cores'**, which are **independent processing units** that can communicate (but do different things at the same time).



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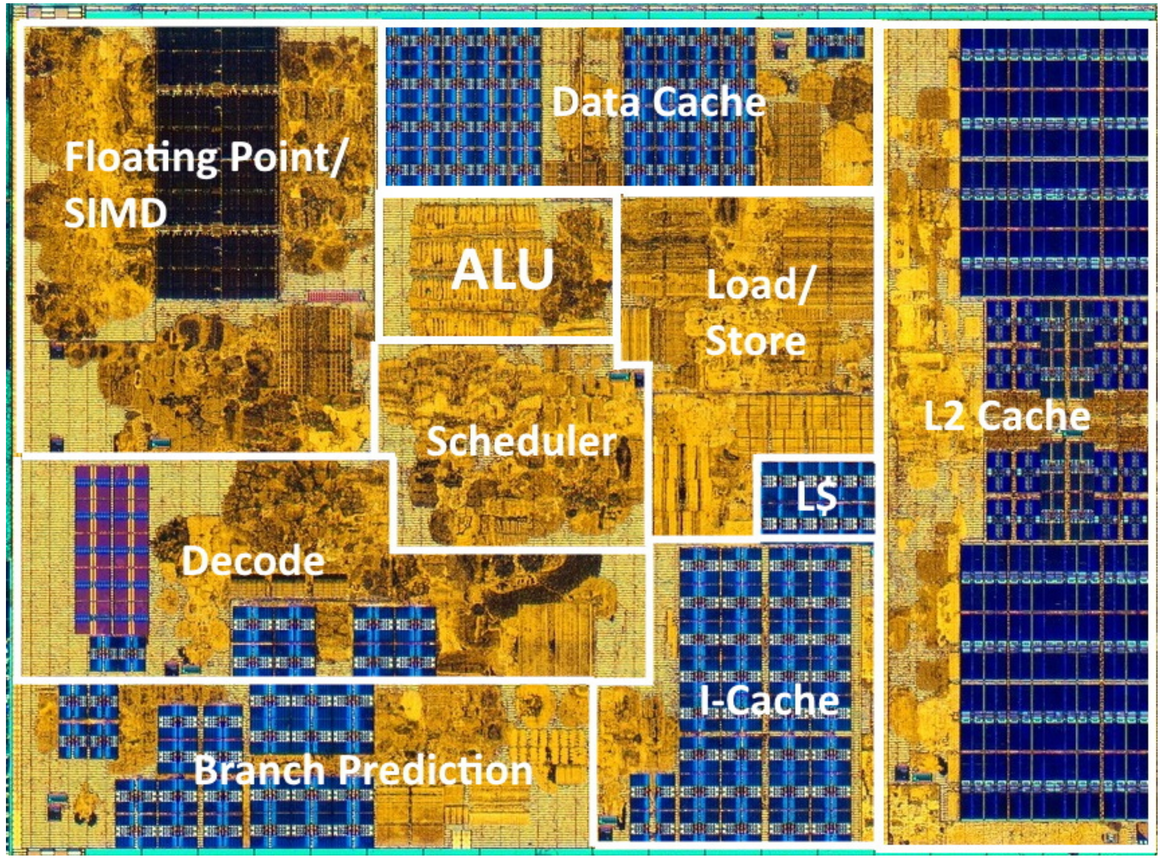
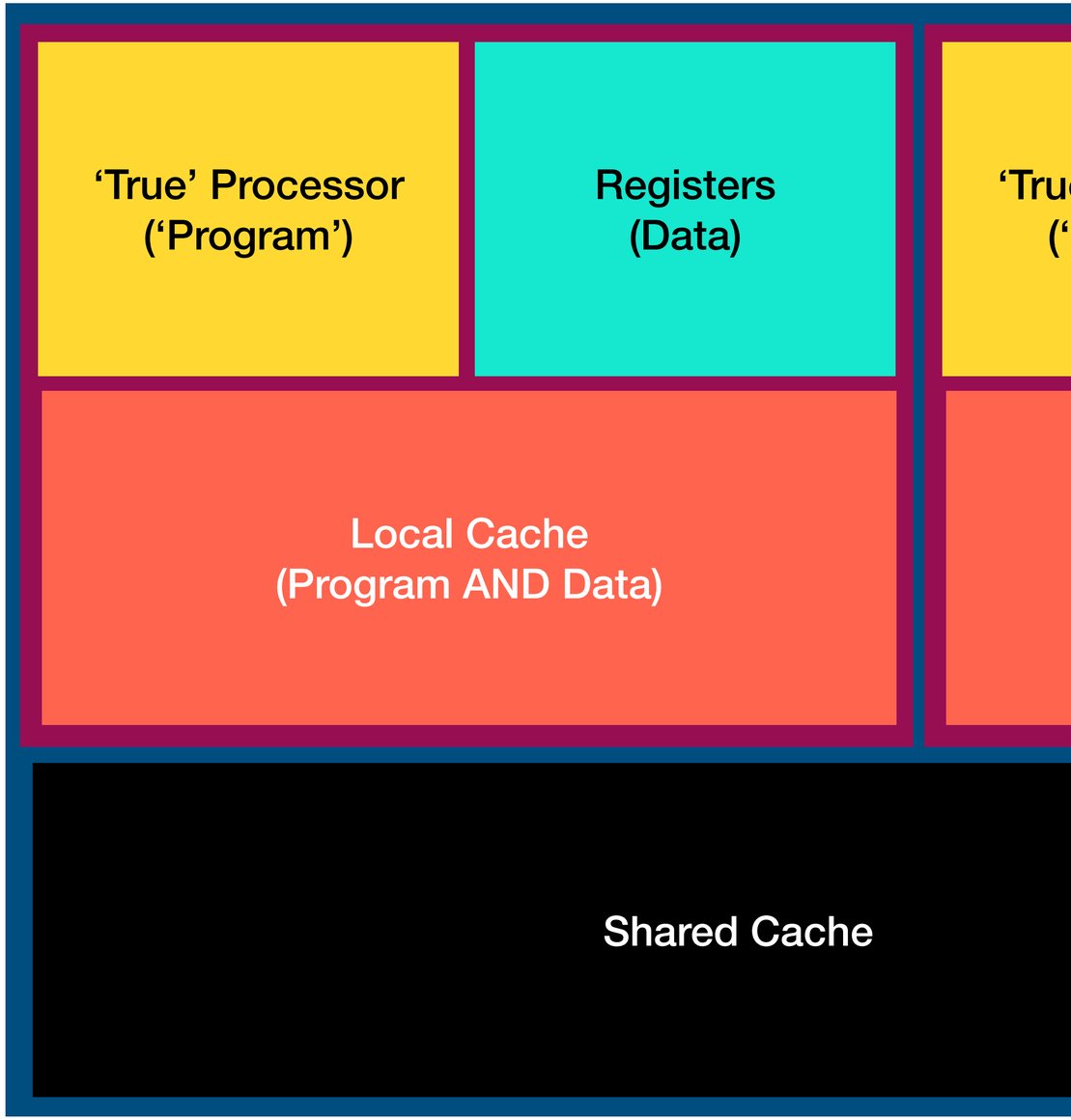


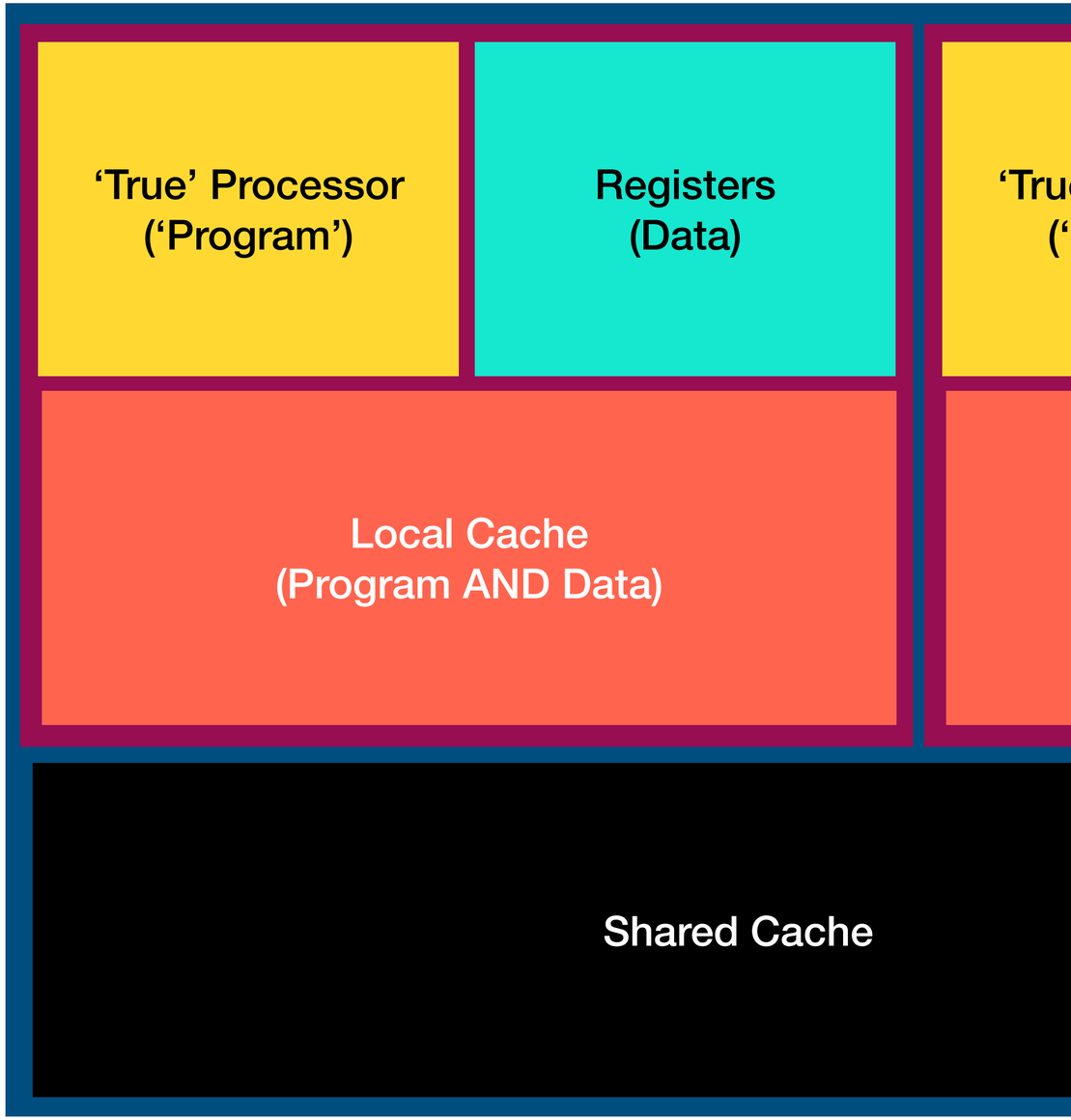
CPU layout

- The program you are trying to execute is, in its most base form, a **set of instructions** for the CPU to execute.
- Instructions are things like…
  - Add two numbers together
  - Multiply two numbers together
  - Move a piece of data from one location to another



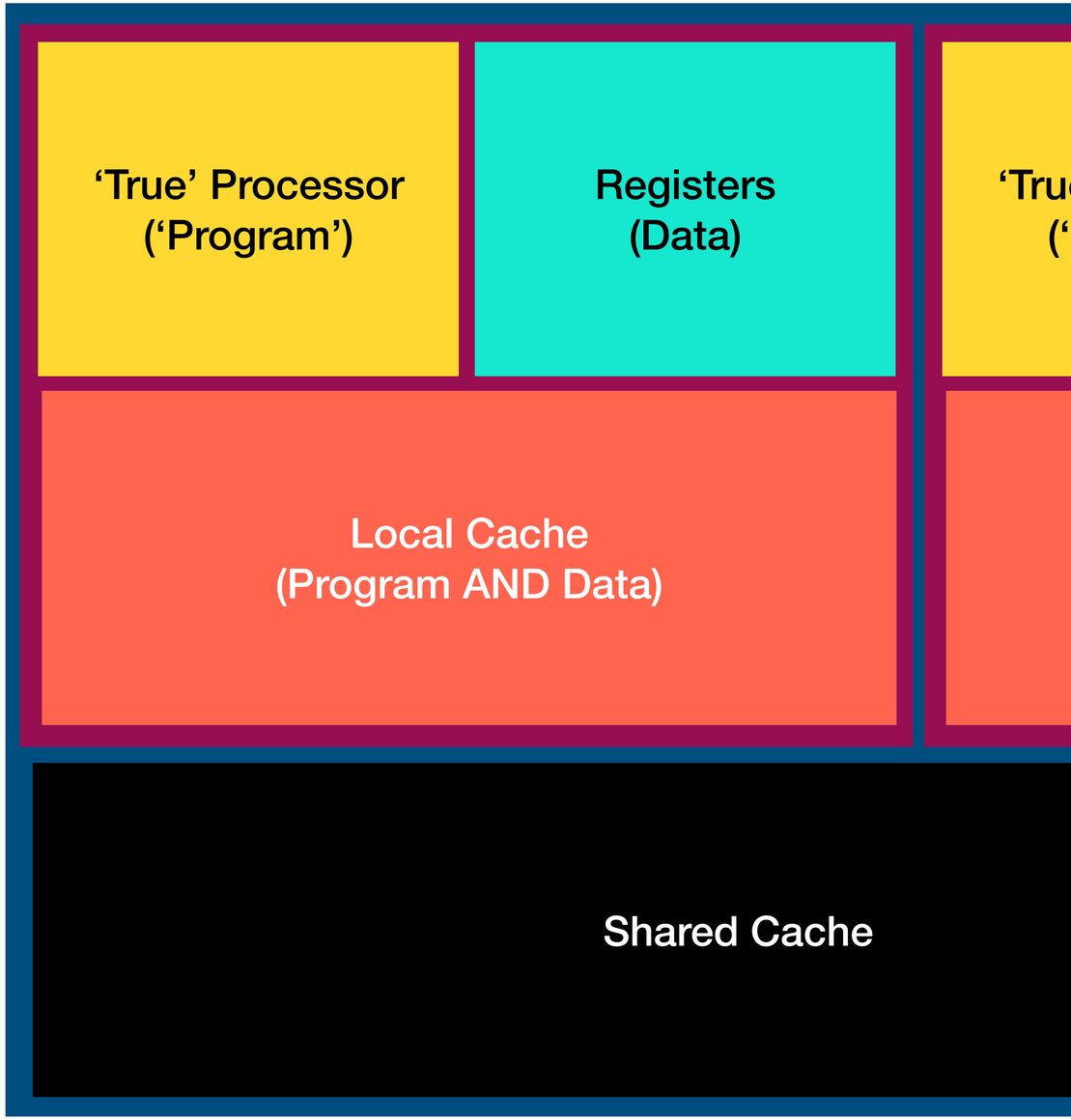
CPU layout

- In the CPU, there are various levels of '**cache**'. These are **small bits** of memory that are **extremely fast** and are co-located with the circuitry for doing the processing.
- Your **program and required data are loaded into the lowest level cache**. **This is** relatively **slow**. The CPU then asks for the next instruction, and it's go time!



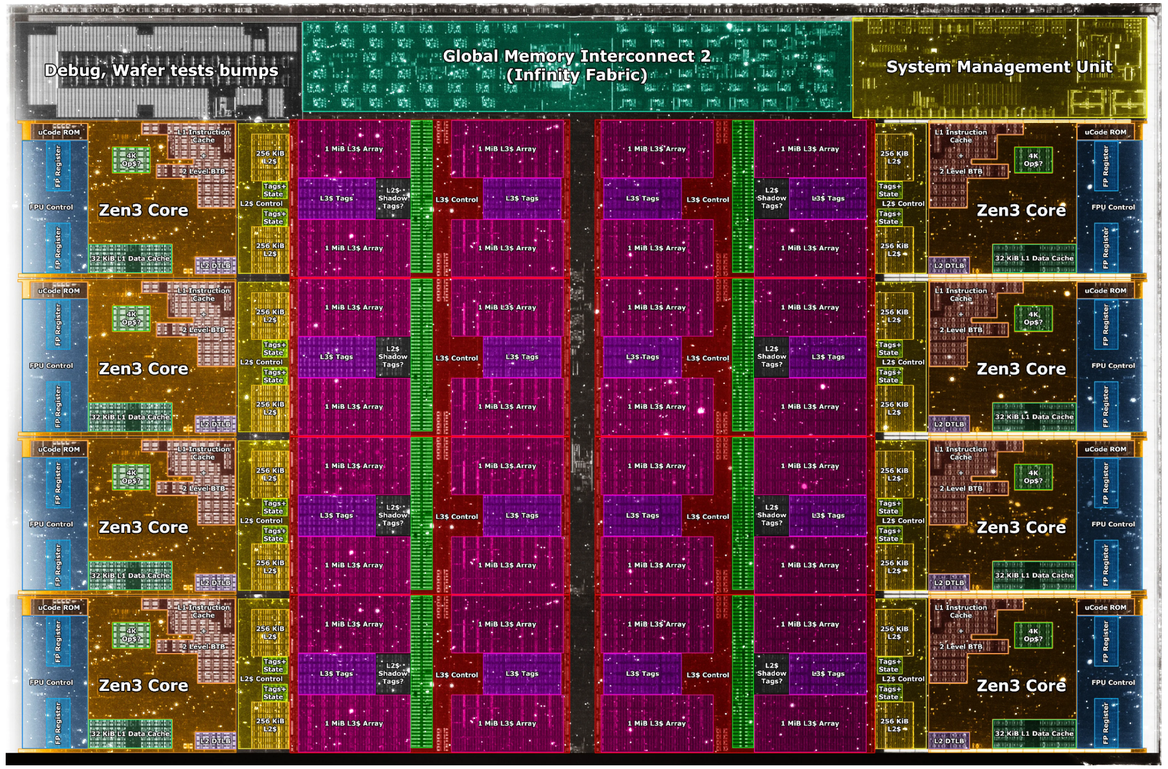
CPU layout

- Next to the CPU there are **registers**. These registers are **extremely fast** and well-connected data storage (there is space for about **700** numbers per core).
- Once you have completed your set of instructions, your **data needs to make its way out of registers back into main memory**, which is a **slow** process.



Multiple Cores

- Modern CPUs have **many** of these **processing units** all on one chip. Your laptop probably has around 4-12, and server CPUs have 32-128.
- All these cores **share resources**, though (e.g. they have a shared cache, interfaces with main memory), which can **cause contention**!



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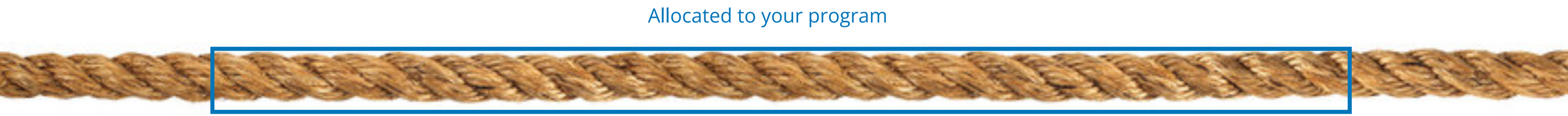

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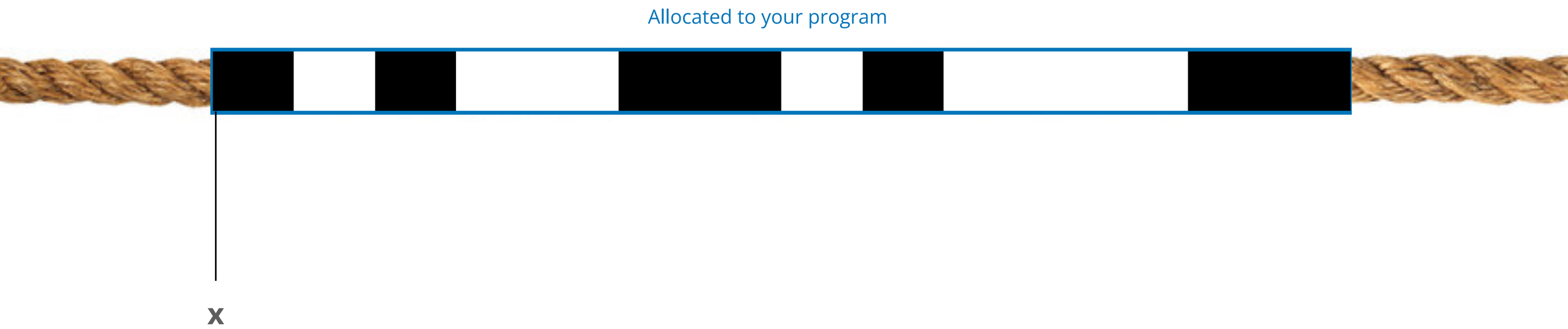

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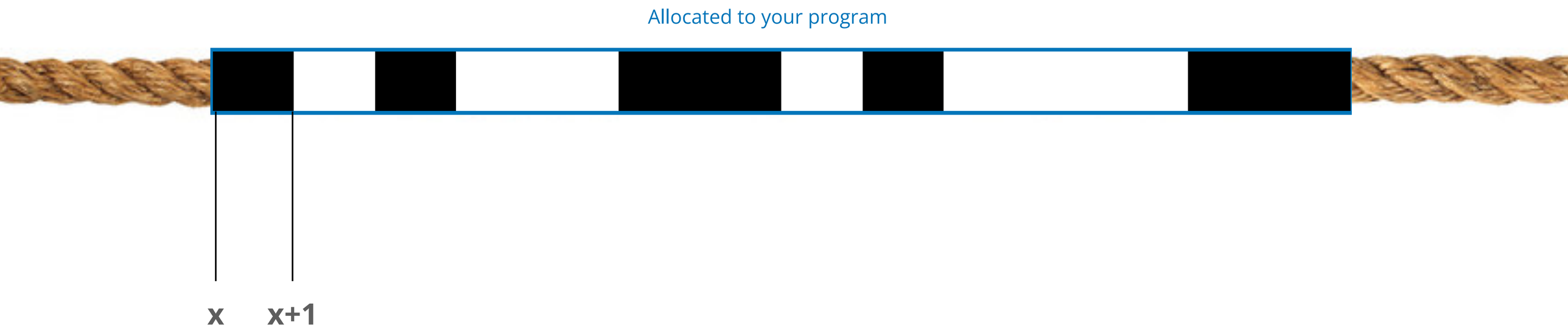

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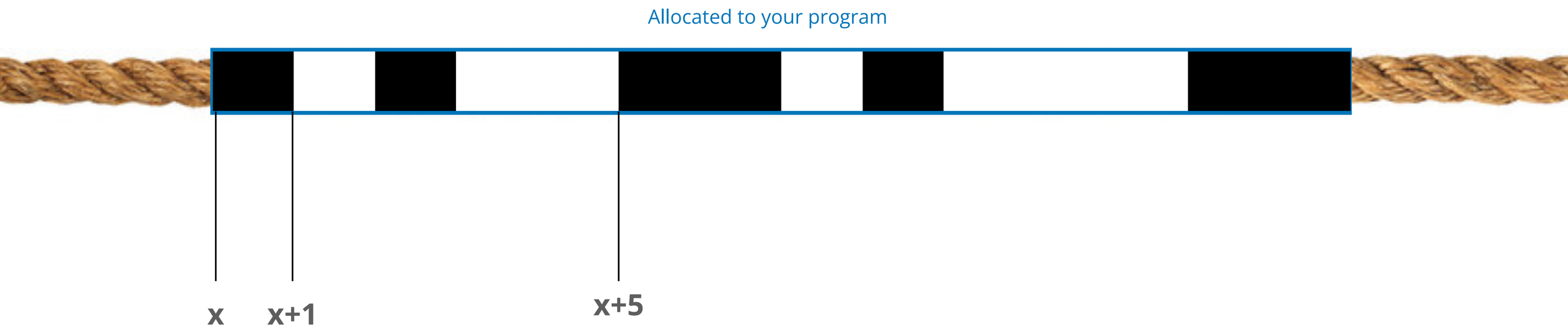
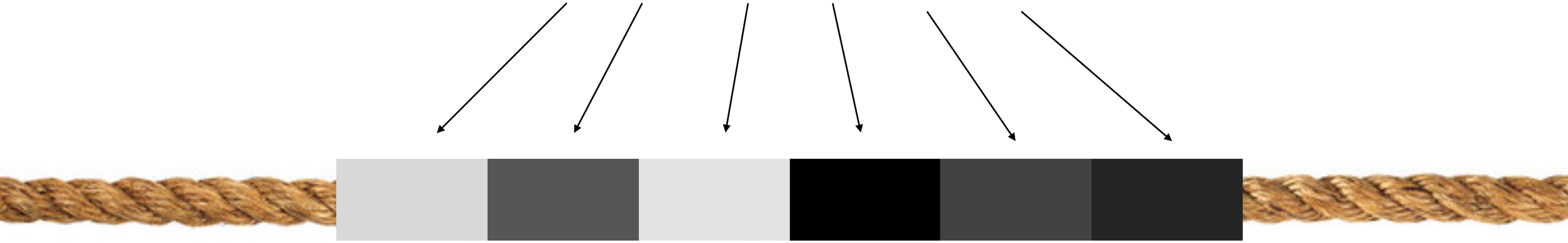


Arrays in Memory

- Arrays (e.g. numpy arrays) are maximally space efficient structures!

[122, 783, 101, 993, 882, 920]



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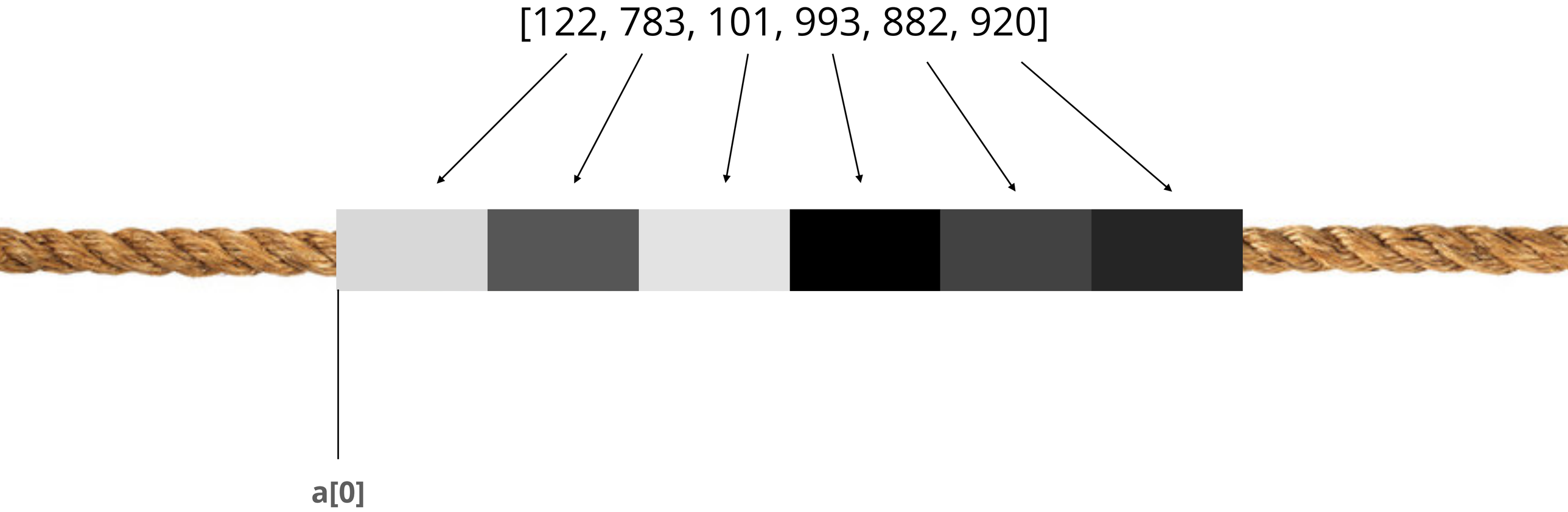

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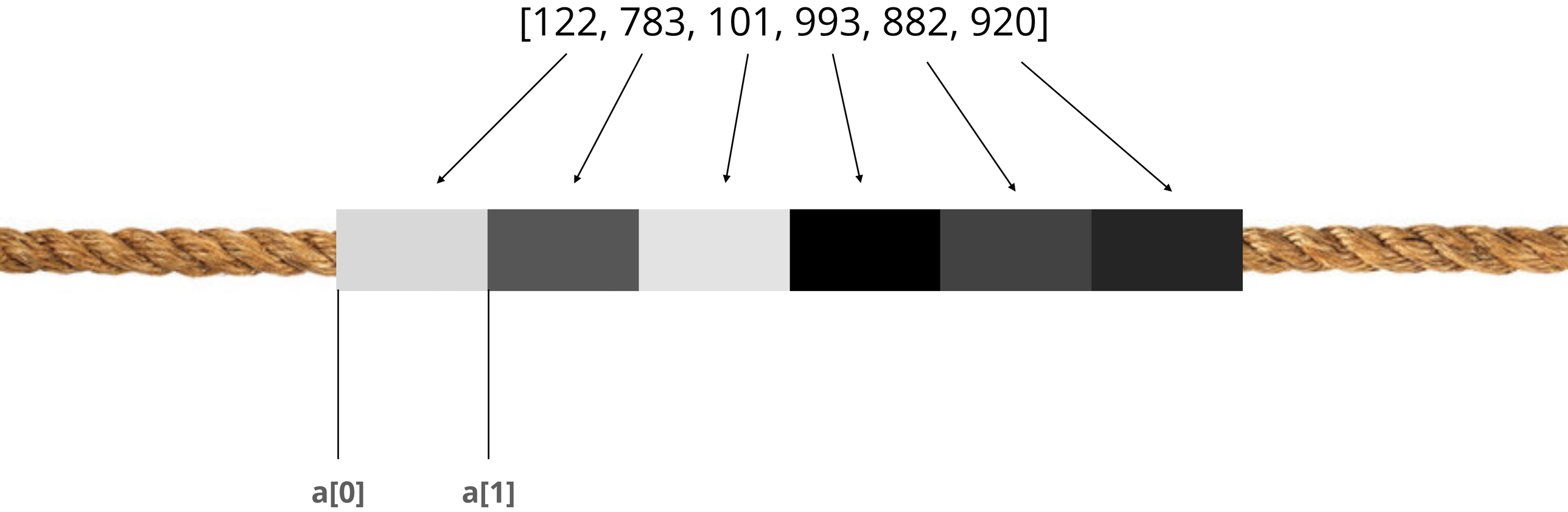

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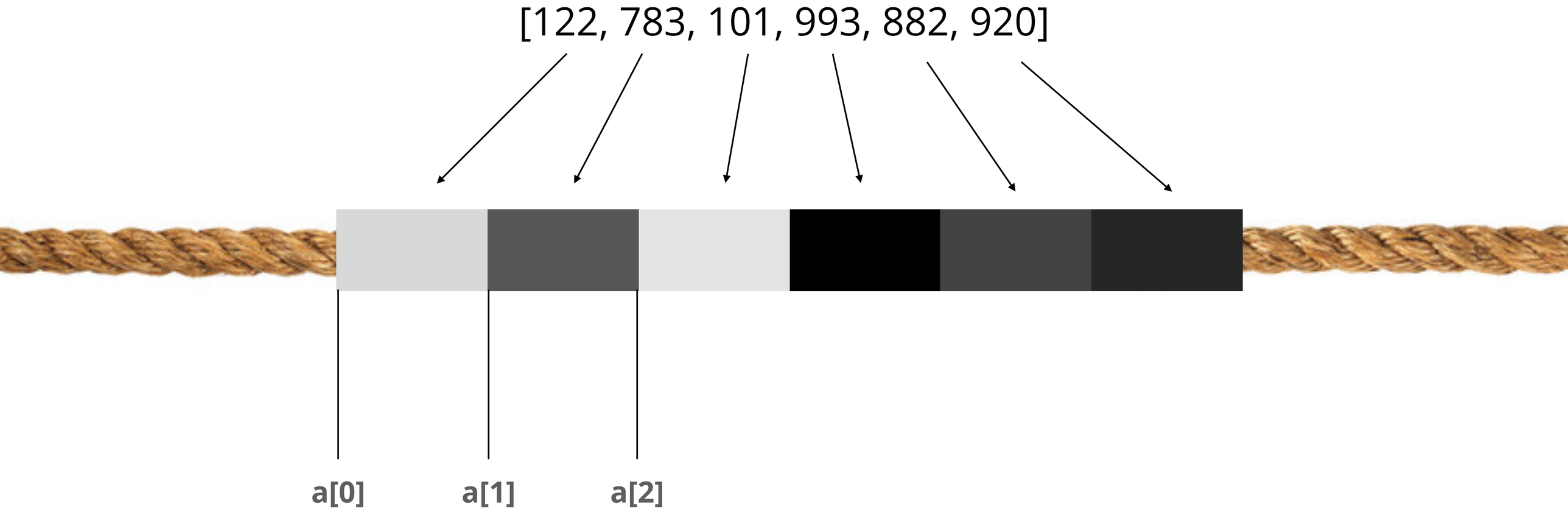

N-dimensional arrays?

- What about 2D arrays..?
- We just stack them together!

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[250, 750, 130, 299, 899, 999]

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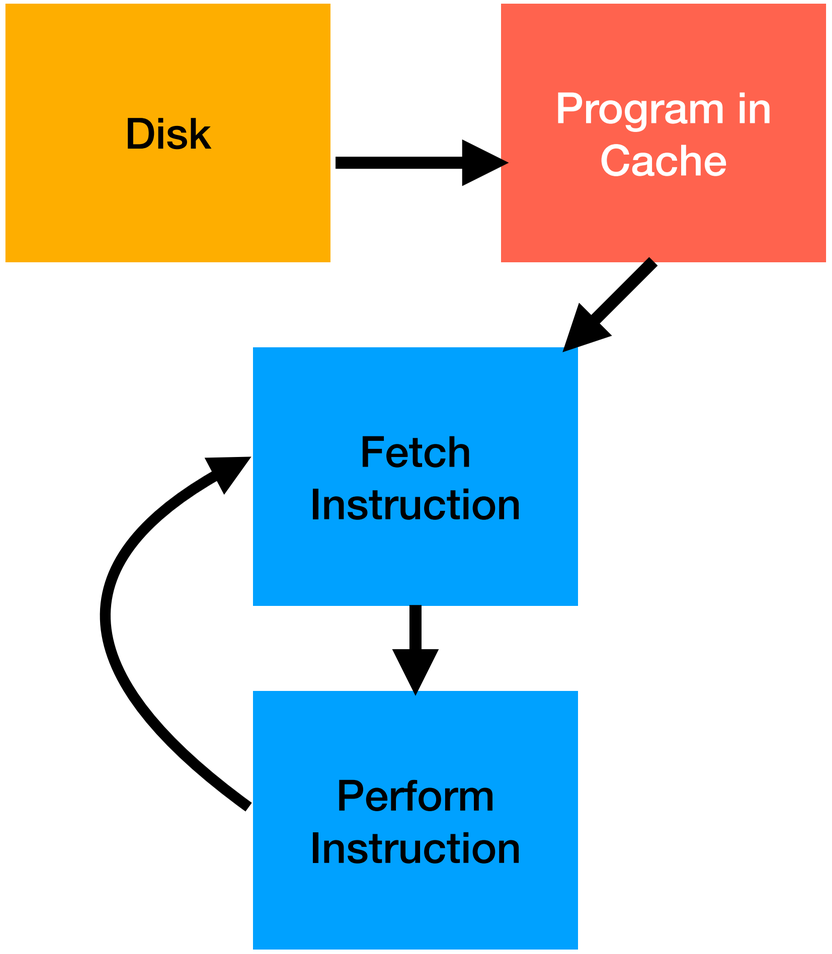
Your program

- Before we talk about how your program actually runs, we need to make a distinction between two different types of software:
  - Compiled software, written in languages like C
  - Interpreted software, written in languages like python

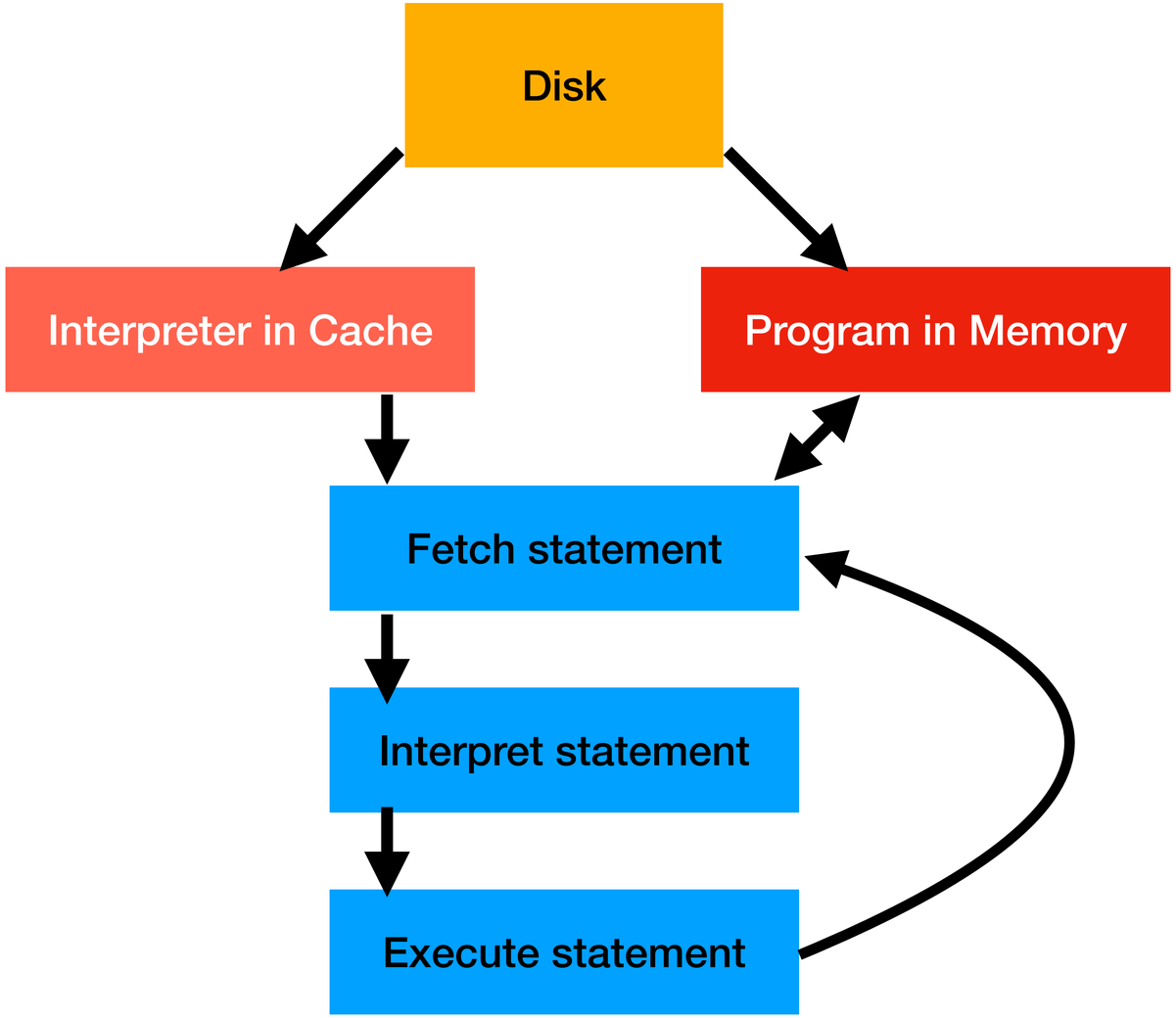
Compiled programs

- A ‘compiler’ turns your **entire** human-readable code into ‘**machine code**’ ahead of time.
- This machine code is **optimized** by the compiler ahead of time, and is hence usually uses **minimal operations** to perform tasks.
- **Execution flow** hence can then take a ‘**simple**’ path through the hardware.



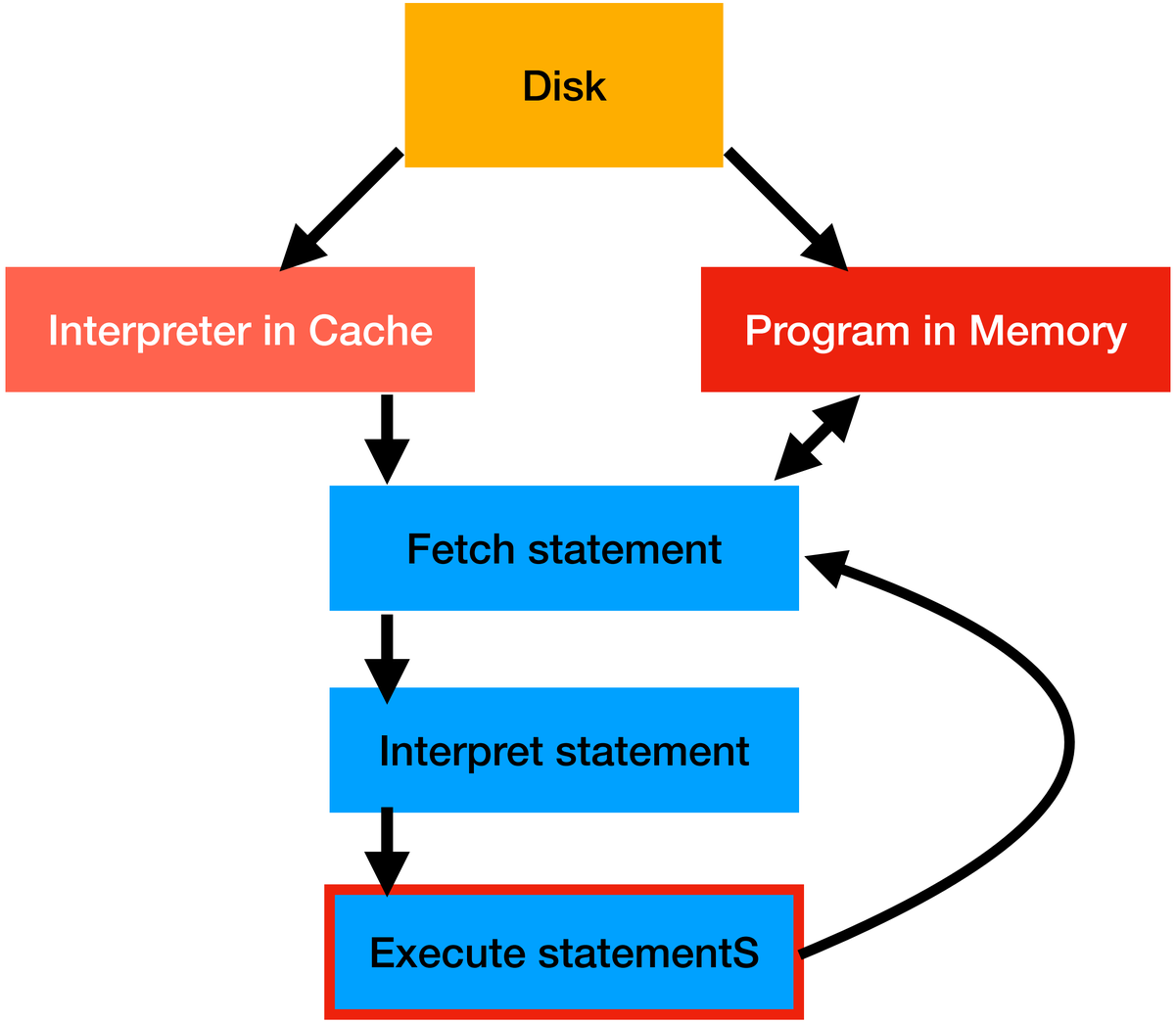
Interpreted programs

- In this case we **piggyback** on another program (the **interpreter**, e.g. CPython for python code) that manages our instructions.
- This leads to a **much more complex** (and hence slower) internal execution flow, due to **constant fetches from main memory**!



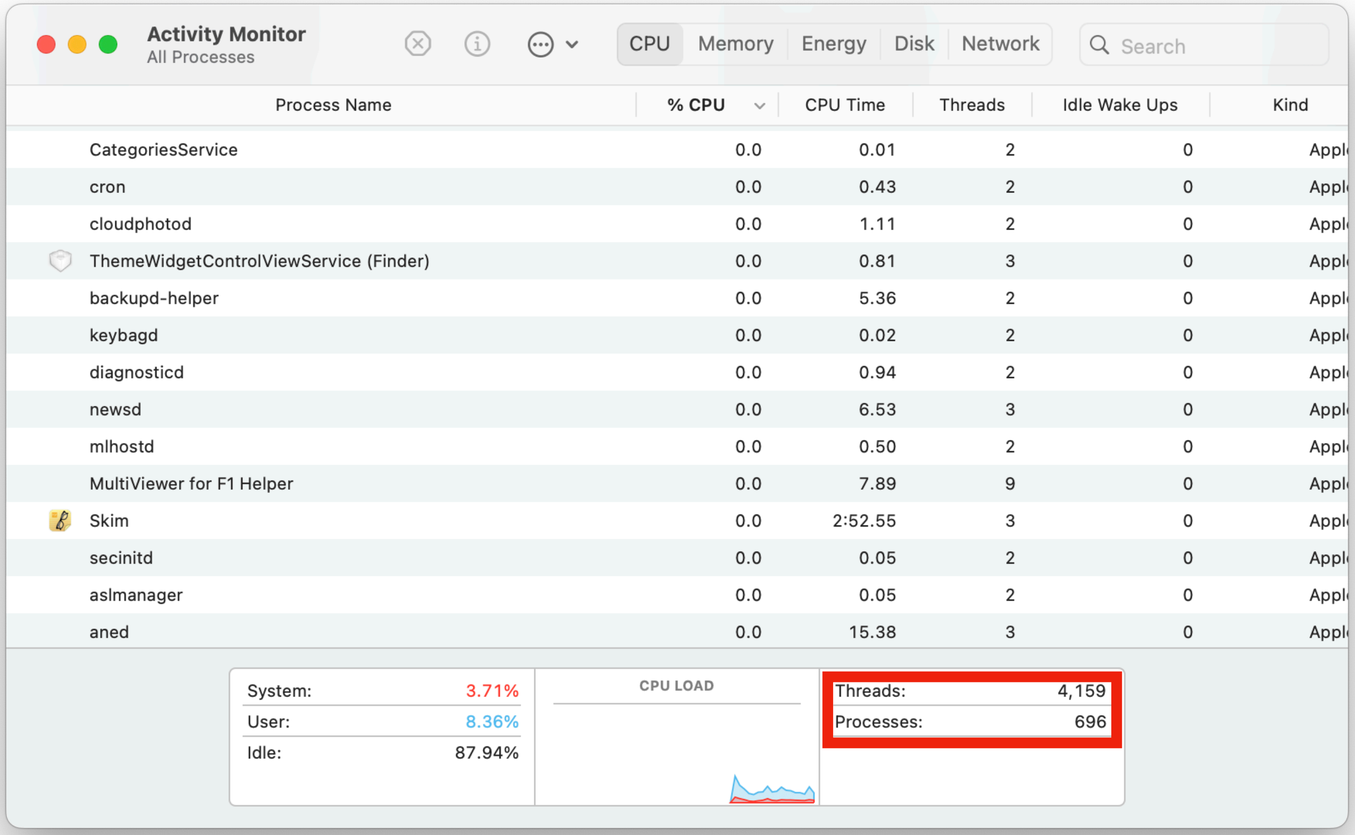
Compiled extensions

- With compiled extensions like numpy, you can '**vectorize**' the underlying operations.
- This **speeds up** code by mixing the flexibility of the interpreted code with the heavy use of caches by the compiled code, by **reducing reads from main memory**!



Being managed by the operating system

- Your programs always run in the context of the operating system.
- Have you ever wondered how you can have **more apps open than cores**?
- All modern operating systems use '**preemptive multitasking**'…



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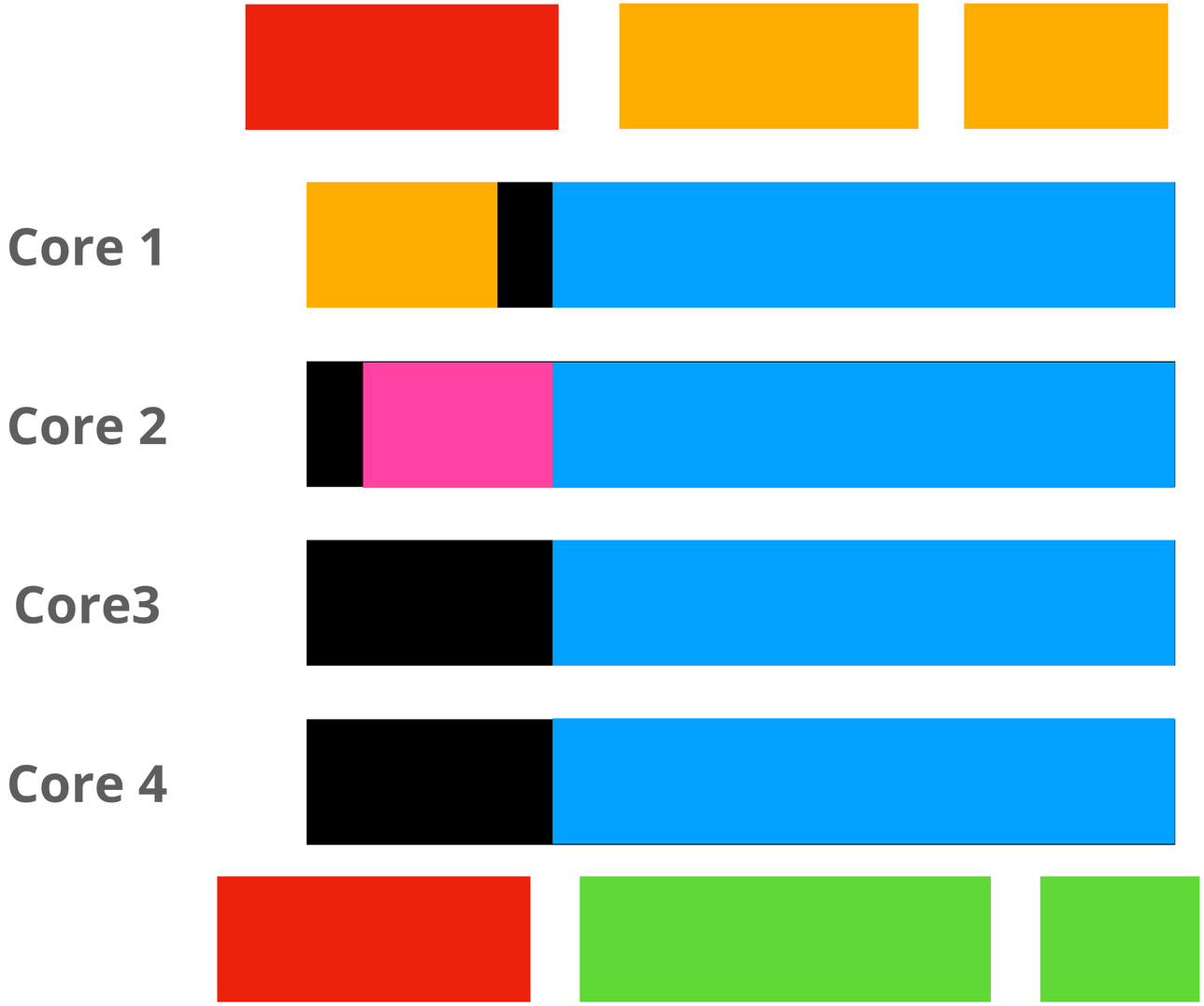
Being managed by the operating system

- The **OS can't steal control back as easily when you are deep in loops**; the CPU will simply ignore the OS.
- You must then be careful when running multi-threaded programs on your laptop; **don't assign them to all your cores**!



Summary

- A computer takes inputs, stores them in memory, performs processing on them, and writes them to an output.
- In a standard computer, the disk is the storage, RAM is the memory, and the CPU does the processing.
- Modern CPUs have multiple layers of caching and many cores that try to help them be as fast as possible.
- RAM can be thought of as a continuous string that stores information.
- Interpreted languages like python have compiled extensions to help extract good performance whilst maintaining flexibility.